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NPIC/TP-18/63
July 1963

TECHNICAL PUBLICATION

KH-7 CAMERA SYSTEM
PART I

CIA DIA

18.1

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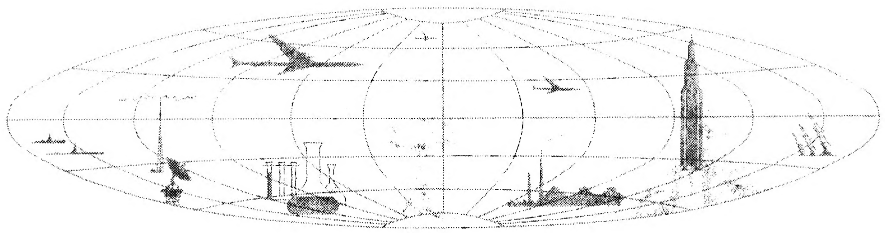

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KH-7 CAMERA SYSTEM
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PREFACE

This publication presents general technical information for the early exploitation of photography obtained by the KH-7 camera system. The scales, tables, charts, and graphs presented are for the photo-interpreter's use in determining approximate sizes, scales, and relative orientation of objects or images and is not meant to take the place of the more precise mensuration parameters.

Technical information with complete mathematical analysis for reduction of quantitative data will be published as Part II of this manual.

The following data will be made available for each mission on a timely basis:

1. Camera Data: Operational focal length, lens distortions, ramp informations, film velocity, image motion data, film type, filters, exposures, slit width, and expected resolution.
2. Stellar/Index Unit Data: Calibrated focal lengths, distortions, grid intersections, exposures, etc.
3. Orbital Data: A one second orbital ephemeris for each second of camera operation, including velocity, altitude, geographic position, time of operation, etc.
4. Vehicle Attitude: Pitch, roll, and yaw, and rates of each when available.

INTRODUCTION

The KH-7 camera system consists of a single strip camera, a stellar camera, and an index camera.

The strip camera utilized in the KH-7 system will provide relatively large-scale, high-acuity photography of selected target areas in either monoscopic or stereo modes. It is designed to provide the photo-interpreter with an image considerably larger and with better ground resolution than that provided by the present KH-4 surveillance system. The strip camera can roll about its longitudinal axis to either side of the ground track in increments of 0.709 degrees to a maximum of plus or minus 44 degrees 40 minutes. This allows centering of the target area in the format of the strip frame. Also the camera is yawed around its vertical axis to eliminate coriolis force.

The strip camera consists of a rotating mirror, a 77-inch focal length folded lens system, and a cylindrical platen. (See Figure 1 for details.) The camera system may be operated in several modes: monoscopic strip, stereoscopic superimposed strips, or lateral pairs of strips. Any of these modes are available in any of the roll positions. (See Table No 1.)

Table No 1. Roll Positions Available In Degrees (Left or Right)

0 Vertical	11.344	22.688	34.032
0.709	12.053	23.397	34.741
1.418	12.762	24.106	35.450
2.127	13.471	24.815	36.159
2.836	14.180	25.524	36.868
3.545	14.889	26.233	37.577
4.254	15.598	26.942	38.286
4.963	16.307	27.651	38.995
5.672	17.016	28.360	39.704
6.381	17.725	29.069	40.413
7.090	18.434	29.778	41.122
7.799	19.143	30.487	41.831
8.508	19.852	31.196	42.540
9.217	20.561	31.905	43.249
9.926	21.270	32.614	43.958
10.635	21.979	33.323	44.667

The film width is 9.460 inches with variable length to each strip depending on operation parameters. This system will produce an image at a nominal scale of about 1:90,000, and the nominal strip will be about 12 nautical miles (nm) in width.

The lens film resolution will be approximately 2.5 feet with proper camera operation.

Two time tracks are recorded on the film with a binary time word recorded on each track every .8 second.

Yaw slits are exposed on both sides of the film as an aid in attitude analysis.

THE STRIP CAMERA

DESCRIPTION OF THE STRIP CAMERA

The strip camera is a 77-inch focal length folded lens system consisting of a primary rotating mirror, a meniscus lens, a stationary primary mirror, a diagonal mirror, field flatteners, a slit plate, and a rotating platen.

The rotating mirror moves to forward and aft positions to produce 30 degree convergent photography for the stereo and lateral pair operating modes. In the mono strip mode the mirror is stationary at 45 degrees from the axis of the lens system. This is a narrow angle lens system since the angle of coverage is only 6.4 degrees with a half angle of 3.2 degrees across ground track. The primary mirror and diagonal mirror focus the image through the slit onto the rotating platen.

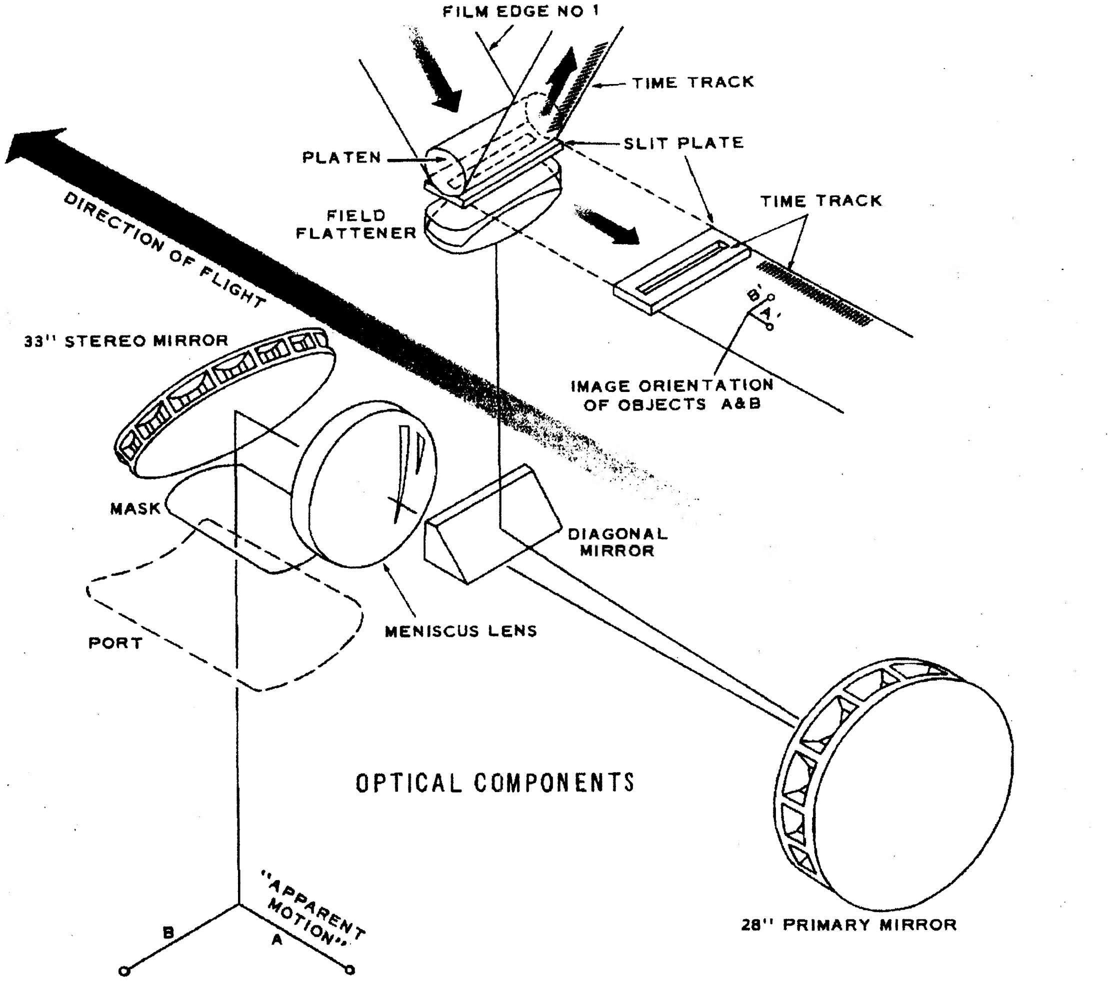

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FIGURE 1. KH-7 CAMERA LENS SCHEMATIC.

The speed of the rotating platen is the controlling factor in production of sharp, distortion-free images and therefore is of utmost importance to the intelligence community. (See "Discussion of Strip Camera".) This cylindrical platen moves at variable speeds and carries the film past the image forming slit at a speed compatible with the movement of ground images past the slit. When operating at the proper speed, this platen will enable the camera to produce sharp images with high resolution. (See Table No 2.)

A pair of fiducial lines will be on the film, one on each edge, rather than fiducial marks. These lines will be the same distance apart at all times, since they are being exposed at the same time that the image is exposed, and will be one controlling factor in mensuration and determination of coverage and size of objects. In addition to these two

Table No 2. Lengths of Film Strips in Inches With Varying Film Speeds and Lengths of Operations

Film Speed Inches Per Second	2.0	3.0	4.0	5.0	6.6	9.0	12.3	25.0	50.0	102.4
2.022	4.04	6.07	8.09	10.11	13.35	18.20	24.87	50.55	101.10	207.05
2.132	4.26	6.40	8.53	10.66	14.07	19.19	26.22	53.30	106.60	218.32
2.242	4.48	6.73	8.97	11.21	14.80	20.18	27.58	56.05	112.10	229.58
2.352	4.70	7.06	9.41	11.76	15.53	21.17	28.93	58.80	117.60	240.85
2.462	4.92	7.39	9.85	12.31	16.25	22.16	30.28	61.55	123.10	252.11
2.572	5.14	7.72	10.29	12.86	16.98	23.15	31.64	64.30	128.60	263.38
2.682	5.36	8.05	10.73	13.41	17.70	24.14	33.00	67.05	134.10	274.64
2.792	5.59	8.38	11.17	13.97	18.43	25.13	34.35	69.80	139.65	285.90
2.902	5.81	8.71	11.61	14.52	19.15	26.12	35.70	72.58	145.15	297.17
3.012	6.03	9.04	12.05	15.07	19.88	27.11	37.06	75.33	150.65	308.53
3.122	6.25	9.37	12.49	15.62	20.61	28.10	38.41	78.08	156.15	319.80
3.232	6.47	9.70	12.93	16.17	21.33	29.09	39.76	80.83	161.65	331.06
3.343	6.69	10.03	13.37	16.72	22.06	30.08	41.12	83.58	167.15	342.23
3.453	6.91	10.36	13.82	17.27	22.79	31.08	42.48	86.33	172.65	353.50
3.564	7.13	10.69	14.26	17.82	23.52	32.07	43.83	89.10	178.15	364.95
3.674	7.35	11.02	14.70	18.37	24.25	33.06	45.19	91.85	183.70	376.02
3.784	7.57	11.35	15.14	18.92	24.98	34.06	46.54	94.60	189.20	387.48

Length of Operation in Seconds

lines, there will be four yaw slits, two on each edge of the film. Each pair of slits is offset from the image slit, one on either side, so that the same image is exposed at two different times. By analyzing the image displacement from slit to slit, roll and yaw can be determined.

STRIP CAMERA FEATURES

Lens: Meniscus Maksutov, Concave-Convex Type.

Rotating Mirror: Plano Surface Mirror 33 Inch Diameter.

Focal Length: 77 Inches.

Slit Plate: Three Slit Widths Available (not changeable during operation).

Primary Mirror: 1st Surface Spherical Mirror (focusing mirror).

Diagonal Mirror: Rectangular Flat Mirror.

Field Flattener: Two Lens Elements (Chromatic Aberration Corrector).

Film Load: 3,000 Feet, 9.460 Inch Width.

Format Size: 8.718 Inches (variable length).

DISCUSSION OF STRIP CAMERA

A strip camera is primarily a motion recording device which stabilizes an image in the focal plane by moving the film past a stationary slit at the same speed as the image moves past the slit. When these two motions are in synchronization, a high resolution image is recorded on the film. Since the film speed and image speed are difficult to establish in an orbiting vehicle, a discussion of variations caused by changes in speed is necessary.

Assuming a stable vehicle, the camera can be operated at near the proper speed, and images formed are very close to precise scale; however, as the speed of the film image combination varies away from the synchronous position, distortion will occur along the line of flight. This distortion or smearing of images is a direct result of film-image speeds, and with the speed available in the KH-7 camera system, smear of 130% is possible along the flight path.

Smear is not the only type distortion apparent in strip photography since a mismatch of film-image speed can also cause compression of images along the flight path. If film speed is too fast for the image, elongation occurs, and if the film speed is too slow for the image, compression occurs.

Any change of film speed will cause elongation or compression of images along the flight path, and because of this, it is very difficult to determine sizes of objects in that direction. A high order of elongation or compression is readily apparent to the trained eye; however, a small order of elongation or compression will make distortion of the size and shape of objects difficult to detect. If the speed of the film changes during exposure, a differential distortion pattern will result in trapezoidal shapes of rectangular objects and curving lines that should be straight.

Since the speed of the film is applicable in only one direction, there is no distortion across the film with a stable vehicle, and all distortions caused by incorrect film speed are in the longitudinal direction of the film (parallel to flight path). Since the vehicle is not a stable platform, it is possible to have distortions caused by vehicle motion in the pitch, roll and yaw planes. There are two separate motions, static and dynamic conditions, in each of the planes. The static condition is when the vehicle is rolled, pitched, or yawed from its nominal position and remains in this position throughout the exposure. The dynamic condition is when the vehicle is pitching, rolling, or yawing during the exposure. For the static condition, pitch and roll are altitude sensitive because any change in vehicle attitude in these planes will alter the image speed at the center of the lens; since image speed is the one that controls film speed, distortions will occur in the direction parallel to the flight path. In the dynamic condition where movement is occuring during exposure, the motion is translated to the images being recorded, and distortions will occur in either direction, parallel to the flight path or perpendicular to it.

Yaw is not altitude sensitive, but the rotational motion in the dynamic condition is translated to the image the same as the pitch and roll motions are. Under static yaw conditions only small amounts of distortions are evident unless the yaw is excessive.

All of the distortions or smear of images discussed may occur at the same time and on the same exposure; therefore, determination of the exact cause of image distortion is not possible. Part II of this manual will discuss the mathematical approach to the problem of determination of image size and shape with multiple image motion problems.

OPERATING MODES

The KH-7 camera system can produce single strips of photography over a wide range of sizes from a minimum of 4 to a maximum of 387 inches in length; however, normal operations will fall in a much narrower range of 13 to 46 inches in length. (See Table No 2.) The film speeds available are from 2.022 inches per second up to 3.784 inches per second in 64 separate speeds; this allows operation in various portions of the orbit to produce distortion-free photography. (See "Discussion of Strip Cameras".)

When operating in either the stereo mode or in the lateral pair mode, the lengths of strips are controlled by speed of the vehicle and its altitude. The stereo pairs are programmed to produce 100% forward lap, and the lateral pairs are programmed to produce parallel strips with minimum side lap. (See Figures 2 and 3.) In the stereo mode, the rotating mirror is moved to the forward-looking position (15 degrees from the vertical along the flight path or parallel to the flight path); a strip of photography is ex-

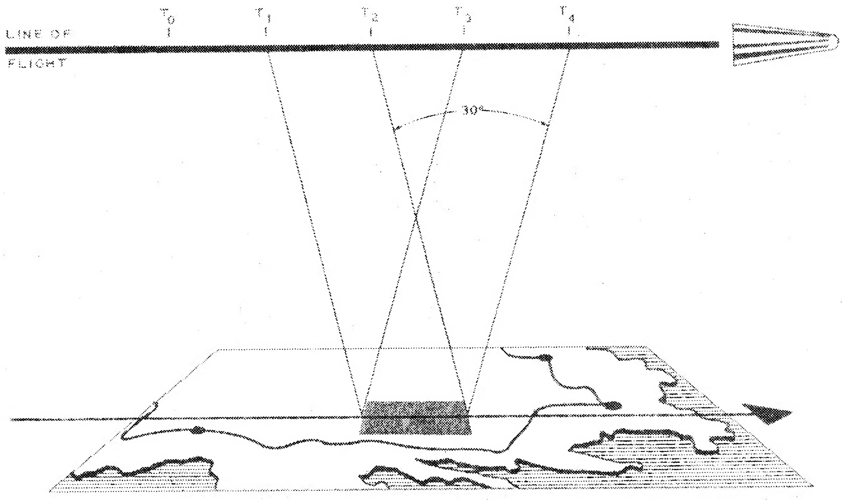

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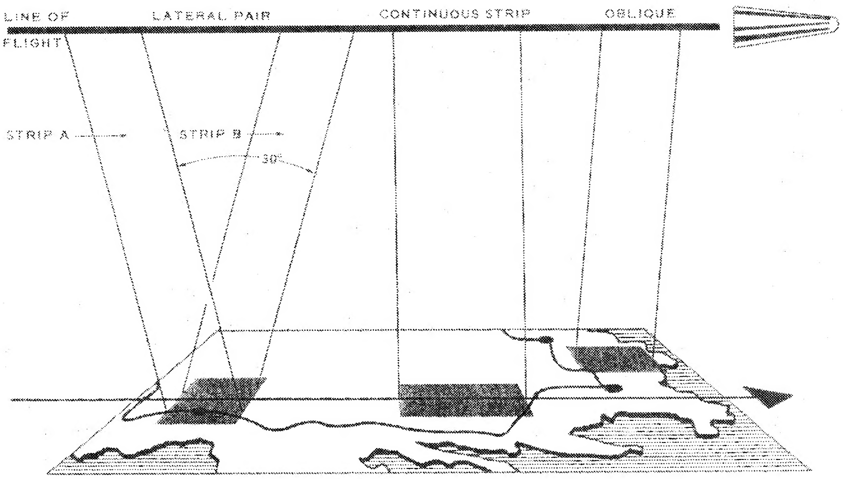
FIGURE 2. STEREO OPERATION SCHEMATIC.



NPIC H-2032 (7/63)

FIGURE 3. OPERATING MODES KH-7 CAMERA SYSTEM.

posed; then the mirror is rotated to its aft position (15 degrees), and the second exposure is made. Some roll is required to produce 100% stereo coverage due to coriolis; therefore, the vehicle rolls to the correct position between exposures. For the lateral pairs, the same 15 degree forward and aft positions are occupied, but the roll position is changed between frames to produce parallel photographs, rather than stereo.

The camera will produce photography over a wide range of coverage area by producing strip, pair, or stereo coverage any place within the 89 degree angular roll coverage available. Any mode may be operated in any roll position, and therefore, a high accuracy pointing camera is available. (See Figures 4 and 5.)

FORMAT AND TITLING

The KH-7 camera format provides a photographic strip of variable length, with a scene width of 8.514 inches as measured between the fiducial lines and excluding the yaw slits. This represents the usable image width. The scene width, if yaw slits are included, is 8.718 inches. (See Figure 6.)

At nominal altitude, the ground coverage width is approximately 12.25 nm. It is not anticipated that altitudes will vary to the extent that width of ground coverage will be less than 10 nm or appreciably more than 20 nm under normal oribtal conditions. (Refer to Table No 3 for altitude/coverage computations.)

The maximum obtainable strip length is approximately 32 feet if film speed and operational time are set to their limits. Strip length, therefore, will vary as film speed and length of camera operation are varied. A total of 64 speed steps are available, from a minimum of 2.022 inches to a maximum of 3.784 inches per second. The length of camera operation may range from 2 seconds to 102.4 seconds. Refer to Table No 2 for the pertinent data. The end of each frame will be denoted by an overexposed section of film, with a small area of distorted imagery caused by film speed acceleration and deceleration in this area. (See Figure 2.) The titling is imprinted in 10-point type on the film edge opposite the edge that contains the time track and is right-reading with the emulsion ~~up~~ down. on film positives. Titles are started 1.5 inches in from the leading edge of the photographic format and are repeated to provide two complete title blocks within every 18 linear inches of film. Explanation of the title increments follows, in order of appearance:

1. Pass Direction Designator ("A" or "D", as appropriate)
2. Pass Number

4 ~~3.~~ Engineering Pass Designator ("E"), if applicable

3 ~~4.~~ Frame Number - The sequence begins with 001 on each photographic pass

5. Mission Number
6. Day-Month-Year (The day is the Z Date of each frame, and the components in this increment are separated by spaces)
7. Security Classification
8. Special Designations (Codeword)

FOCUS

The KH-7 camera system is designed to minimize spontaneous changes in focal length (FL = 77 inches) generated by mechanical or thermal factors beyond the system's control. However, it is recognized that slight shifts in excess of acceptable tolerances may be induced in the image plane by environmental conditions during launch or orbit. Consequently, a focus control assembly is provided for determination

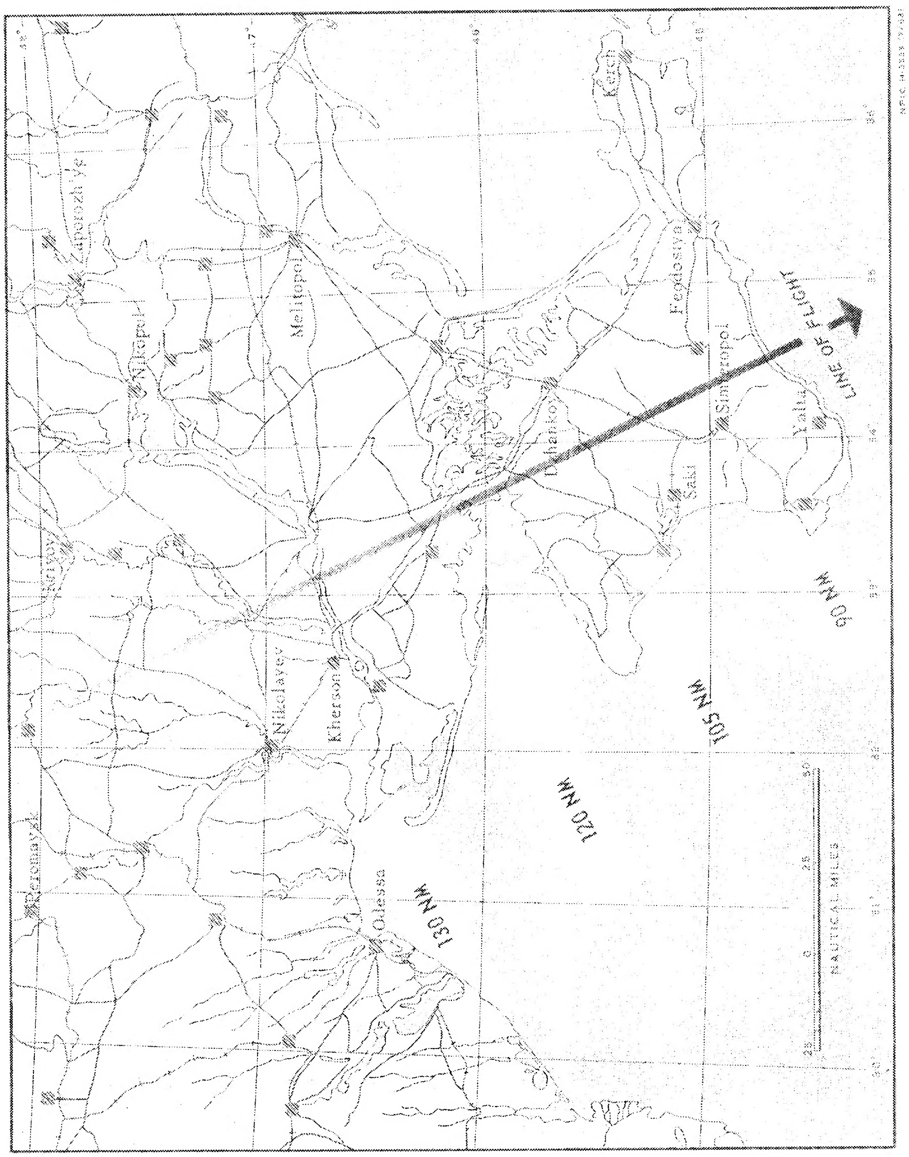


FIGURE 4. POSSIBLE SEARCH AREA FOR VARIOUS ALTITUDES OF KH-7 PROVIDED BY ROLL CAPABILITY.

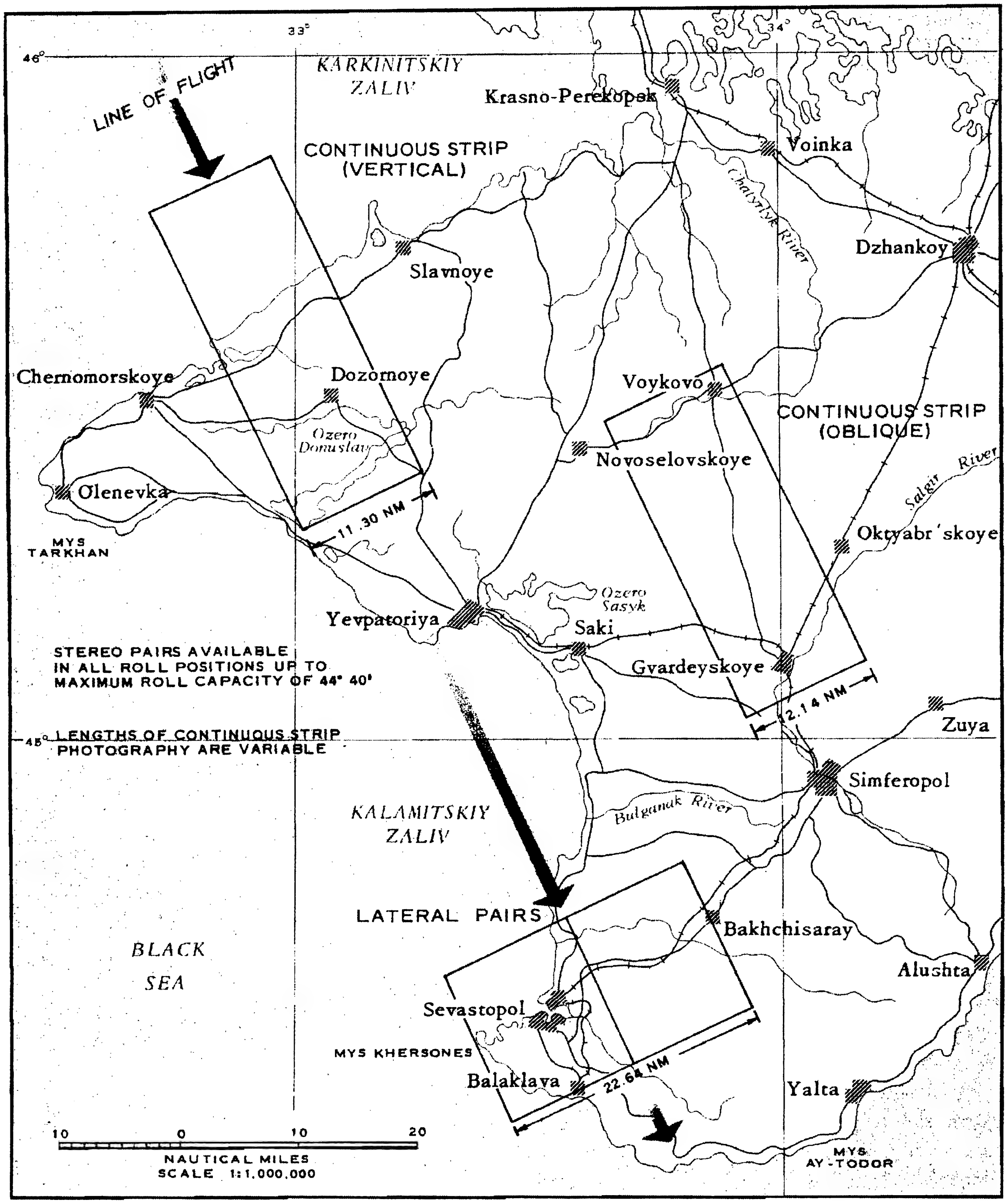


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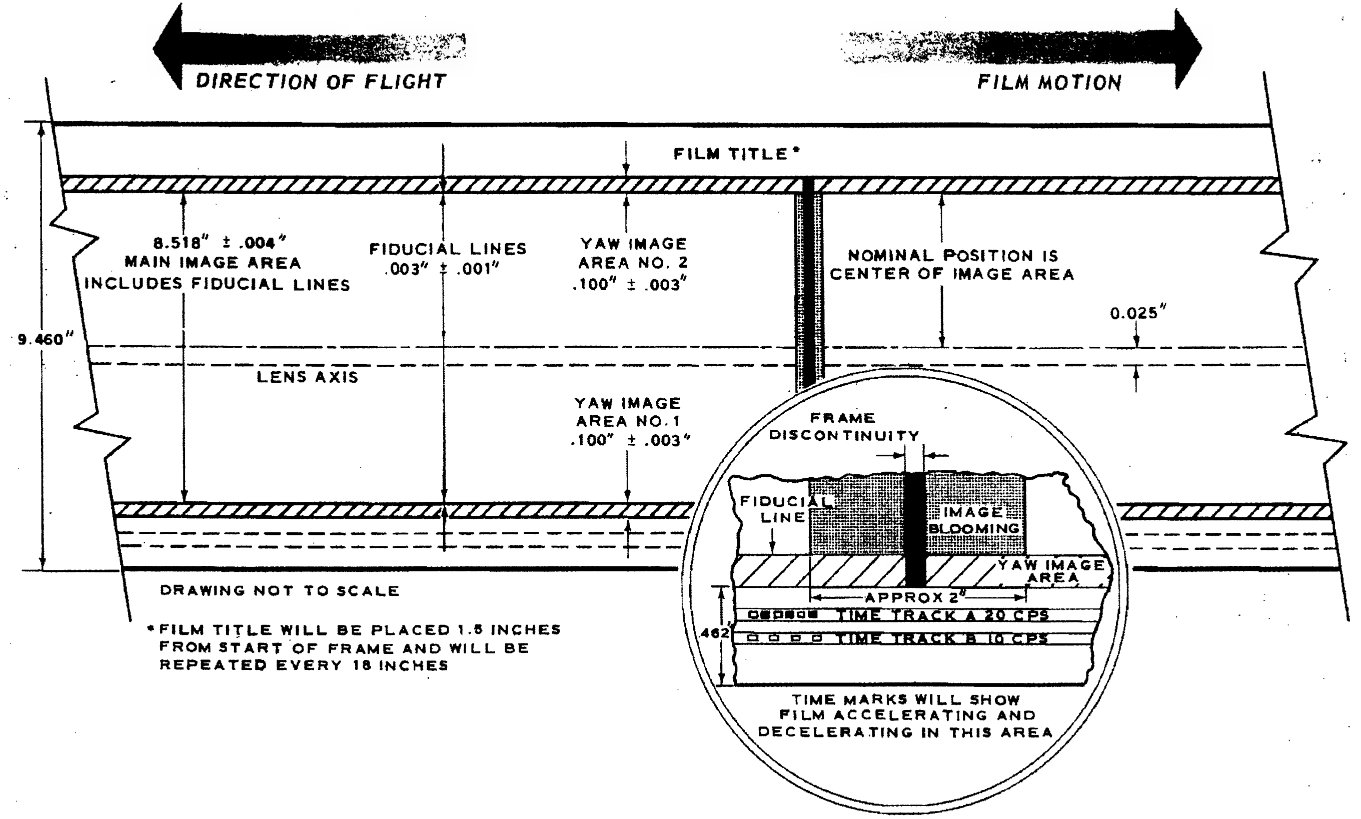
FIGURE 5. TYPICAL EXAMPLES OF CONTINOUS STRIP AND LATERAL PAIR FRAME COVERAGE AT NOMINAL 95 NM ALTITUDE.

Table No 3. Vertical Coverage Table

ALTITUDE NAUTICAL MILES	ALTITUDE FEET	WIDTH COVERAGE NAUTICAL MILES	SCALES	WIDTH COVERAGE IN FEET
90	547,200	10.06	86,275	61,186
90.46	550,000	10.12	86,712	61,500
95	577,600	10.62	91,013	64,556
98.68	600,000	11.03	93,504	67,050
100	608,000	11.18	94,750	67,984
100.33	610,000	11.22	95,062	68,200
102.80	625,000	11.50	97,400	69,886
104.44	635,000	11.68	98,958	71,004
105	638,400	11.74	99,488	71,394
106.91	650,000	11.95	101,296	72,680
110	668 800	12.30	104,225	74,784
111.84	680,000	12.51	105,970	76,056
113.49	690,000	12.69	107,530	77,154
115	699,200	12.86	108,963	78,182
115.13	700,000	12.89	109,088	78,272
116.78	710,000	13.06	110,646	79,390
118.42	720,000	13.24	112,203	80,508
120	729,600	13.42	113 700	81,582
120.89	735,000	13.51	114,540	82,186
123.35	750,000	13.80	116,880	83,864
125	760,000	13.98	118,438	84,980
125.82	765,000	14.07	119,218	85,540
127.46	775,000	14.25	120,776	86,660
129.93	790,000	14.53	123,115	88,340
130	790,400	14.54	123,175	88,380
131.58	800,000	14.71	124,673	89,454
135	820,800	15.10	127,913	91,780
139.80	850,000	15.63	132,464	95,044
140	851,200	15.66	132,651	95,180
143.91	875,000	16.09	136,360	97,840
145	881,600	16.21	137,389	98,578
148.02	900,000	16.55	140,256	100,636
150	912,000	16.77	142,210	101,975
152.15	925,000	17.01	144,152	103,430
155	942,400	17.33	146,864	105,376
156.25	950,000	17.48	148,046	106,226
160	972,800	17.89	151,601	108,776
160.86	976,000	17.98	151,941	109,030
164.47	1,000,000	18.40	155,840	111,818
165	1,003,200	18.46	156,340	112,176
168.58	1,025,000	18.85	159,736	114,612
170	1,033,600	19.00	161,078	115,574
172.69	1,050,000	19.31	163,633	117,406
175	1,064,000	19.57	165,814	118,974
176.81	1,075,000	19.77	167,528	120,204
180	1,094,400	20.13	170,551	122,372
180.92	1,100,000	20.23	171,424	123,000

of the optimal lens-image plane--film-surface plane relationship. The range of focus adjustment is ± 0.010 inches.

In general terms, the focus control assembly evaluates the conditions of focus. When departure from the limits of best focus is detected, the focus output signals (generated by the detector) indicate that an adjustment of focus is required. The focus drive motor, upon command, then shifts the film platen a controlled distance, returning the plane of best focus to coincidence with the film surface plane.



DRAWING NOT TO SCALE

*FILM TITLE WILL BE PLACED 1.5 INCHES FROM START OF FRAME AND WILL BE REPEATED EVERY 18 INCHES

FIGURE 6. KH-7 FILM FORMAT.

TIME MARKS

A time track will be exposed on the film from which correlative data may be extracted. This time track is composed of two separate time tracks, one operating at 10 cycles per second (cps) and one operating at 20 cps. Binary time is recorded in both time tracks for redundancy checks, with the index marks for each track appearing at different intervals (50 milliseconds apart for the 20 cps track and 100 milliseconds apart for the 10 cps track). (See Inset, Figure 6.)

The binary time word is recorded in 23 bits to an accuracy of .1 second and is repeated every .8 second.

The size and variability of this time word and time track precludes early and easy access to the information. The variability of the time track and time word are controlled by the speed of the film moving past the slit; since this is a variable speed, the recording of the time track is variable also. (See "Discussion of Strip Cameras".) The size of the time track is so small that it is difficult to distinguish individual data bits at less than 10-time magnification, and a 25- or 30-time magnification is necessary to adequately read the time track.

STELLAR/INDEX CAMERA

The stellar/index camera system to be employed in the KH-7 system is the same one used in previous KH-4 and KH-6 systems. (See Figure 7.) These S/I units may be operated at varying intervals to produce adequate exposures for attitude determination during the main strip camera operation. A greater film supply than has been available in the KH-4 S/I units will allow more flexibility in the number of exposures and therefore attitude determination.

STELLAR CAMERA

The stellar camera produces photography of the stellar field over a format area 0.9375 inches diameter. A reseau grid is superimposed on the image plane to produce four fiducial marks at certain intersections of the grid and also to produce a grid on the exposure. The orientation of the reseau grid will vary from mission to mission. Calibration data for the camera and its reseau grid will be supplied with other camera data for each mission.

Frame correlation marks will appear on random frames for correlations of stellar frame and index frame.

Only the frame number will be titled on each frame. Frames will be numbered consecutively throughout the mission. Titling information consisting of mission number, date, classification, codeword, and a chart correlating frames to passes will be affixed to the head leader.

Stellar Camera Data

Lens. Cannon f/1.9.

Focal Length: 85 mm.

Cone Angle: 16 degrees.

Shutter Speed: 0.5 second to 6 seconds.

Filter: None.

Film Load: Variable 35 mm by 75 to 250 feet.

Format Size: 0.9375 inches diameter.

Reseau Grid: 2.5 mm calibrated grid.

In the roll positions available, the stellar camera will be photographing a changing star field since the entire package is rolled to these positions. In the case of a negative roll condition, the stellar unit will be pointing at or near the earth's surface; therefore, attitude may not always be available from this source.

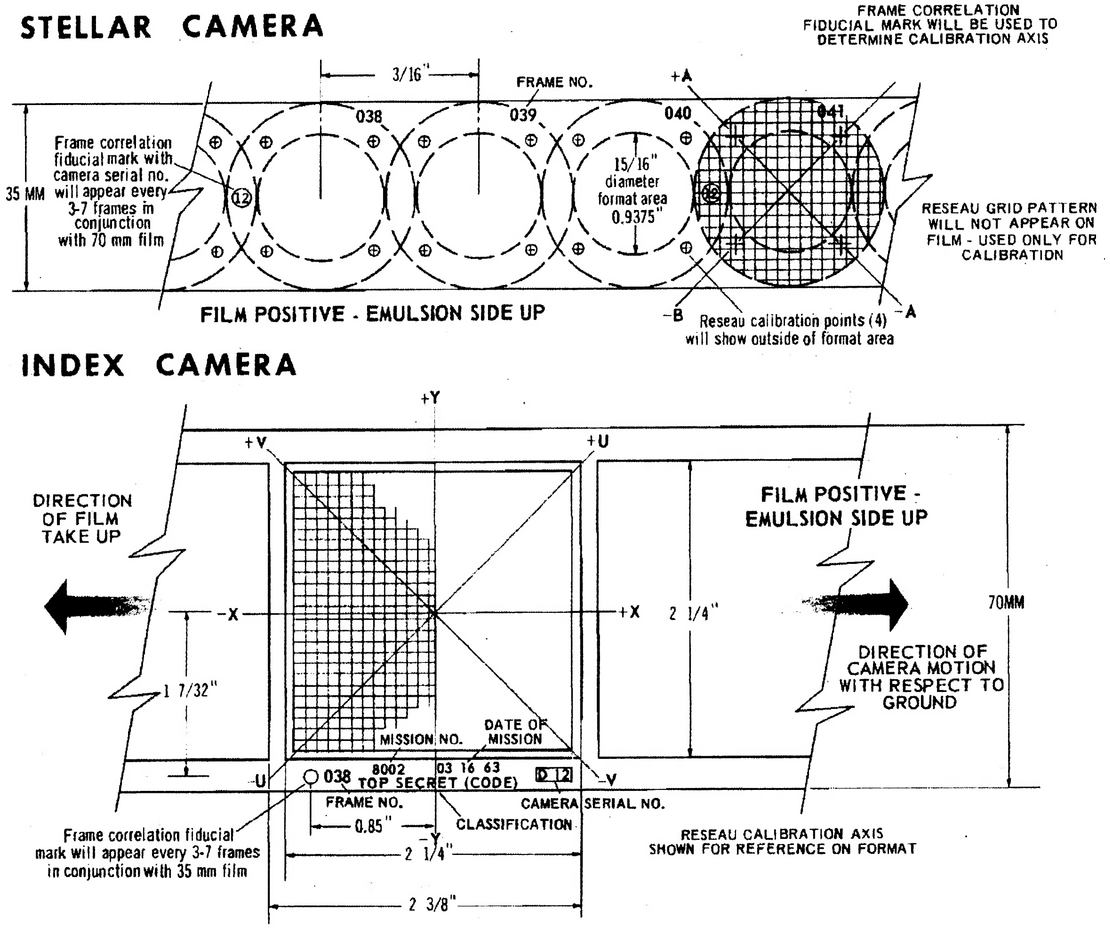

STELLAR CAMERA
FRAME CORRELATION FIDUCIAL MARK WILL BE USED TO DETERMINE CALIBRATION AXIS
3/16"
FRAME NO.
+A
038
039
040
041
Frame correlation fiducial mark with camera serial no. will appear every 3-7 frames in conjunction with 70 mm film
35 MM
12
15/16" diameter format area 0.9375"
RESEAU GRID PATTERN WILL NOT APPEAR ON FILM - USED ONLY FOR CALIBRATION
FILM POSITIVE - EMULSION SIDE UP
-B
Reseau calibration points (4) will show outside of format area
-A
INDEX CAMERA
+Y
+V
+U
DIRECTION OF FILM TAKE UP
FILM POSITIVE - EMULSION SIDE UP
-X
+X
2 1/4"
70MM
1 7/32"
DIRECTION OF CAMERA MOTION WITH RESPECT TO GROUND
MISSION NO.
DATE OF MISSION
-U
038
8002
03 16 63
TOP SECRET (CODE)
D 12
-V
FRAME NO.
CAMERA SERIAL NO.
0.85"
CLASSIFICATION
-Y
Frame correlation fiducial mark will appear every 3-7 frames in conjunction with 35 mm film
2 1/4"
RESEAU CALIBRATION AXIS SHOWN FOR REFERENCE ON FORMAT
2 3/8"

FIGURE 7. STELLAR AND INDEX CAMERA FORMAT AND TITLING.

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INDEX CAMERA

The index camera used is the same as the one in use on other systems, and has a format size of 2.25 inches square with a 2.5 mm reseau grid superimposed on the image. Calibration will be provided for each index camera, and the camera serial number will be recorded on each frame. A frame correlation mark, on a random frame basis, will be imaged for correlation of the stellar camera on one edge of the frame. Titling data will include the frame number, mission number, date, classification, and codeword. Frames will be numbered consecutively throughout the mission, and a chart correlating frames to passes will be attached to the leader.

INDEX CAMERA DATA

Lens: Zeiss Biogon f/4.5.

Focal Length: 38 mm.

Field Angle: 72 x 72 degrees.

Shutter Speeds: 1/125 second, 1/250 second & 1/500 seconds.

Filter: Wratten 21.

Film Load: 70 mm by 125 to 500 feet.

Format Size: 2.25 inches square.

Reseau: 2.5 mm calibrated grid.

Scale: Approximately 1:4,400,000.

The index camera will photograph the portion of the earth directly in line with the roll position of the vehicle since the index camera will be rolled the same amount as the main camera system. This will preclude yaw analysis and stereo coverage between frames taken at different roll positions.

GLOSSARY

The possible degradation of photography by image smearing is inherent in any aerial photographic system. (See Figures 8, 9, and 10.) Hence, one of the major requirements of a system is the capability of reducing or compensating for the various smear-inducing factors. The following are technical terms most commonly encountered with relation to this problem:

IMAGE SMEAR: The degradation or distortion of terrestrial images, usually evidenced by edge-smearing in a direction parallel to the line of flight or approximately perpendicular to it, depending on the factors involved. Elongation or compression of images results, and circular objects may be recorded as elliptical forms.

ALONG-TRACK SMEAR: Image smear parallel to the forward motion or flight path of the camera vehicle.

CROSS-TRACK SMEAR: Image smear perpendicular to the forward motion or flight path of the camera vehicle.

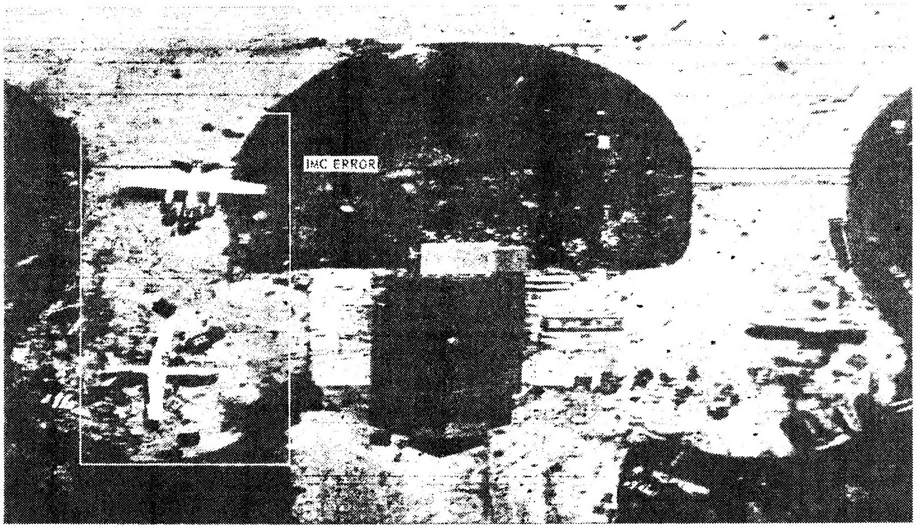

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FIGURE 8. DISTORTION IN STRIP PHOTOGRAPHY.

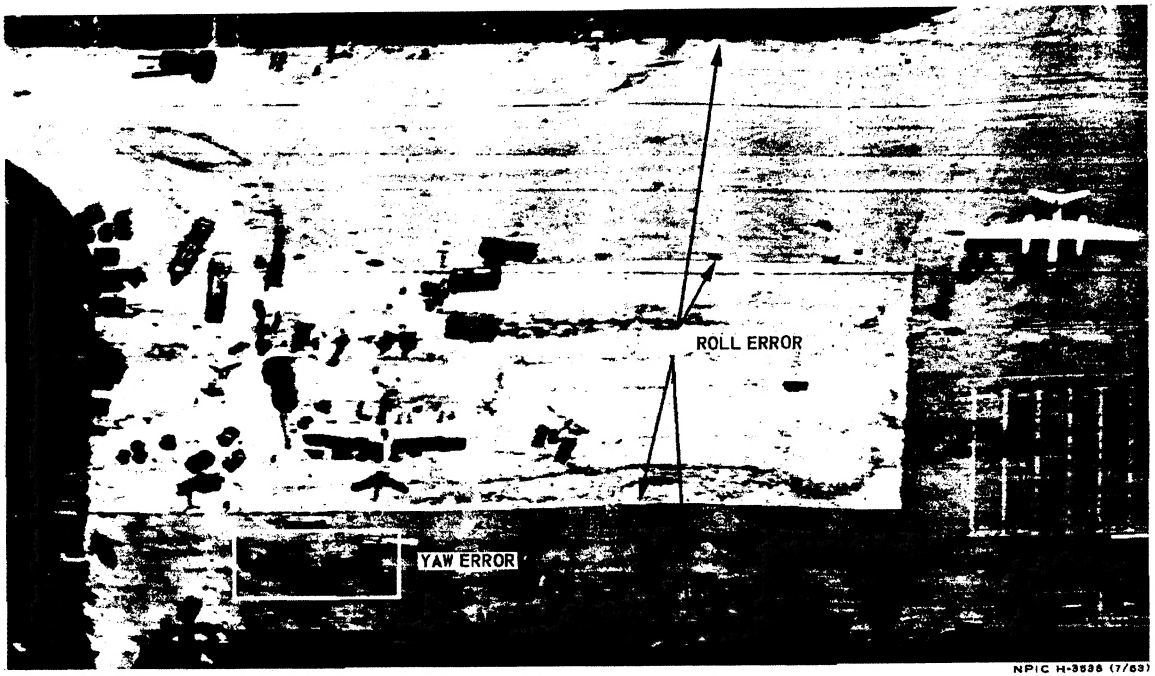

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FIGURE 9. DISTORTION IN STRIP PHOTOGRAPHY.

FILM SPEED: The rate at which the film is advanced in the camera as a means of compensation for the relative motion between terrestrial images and the camera. If too slow, images of ground objects will be compressed; if too fast, images will be elongated.

PITCH: Movement of the vehicle about its lateral axis. Pitch deviations may be negative or positive with relation to the nominal reference angle and alter the camera altitude over ground objects.

PITCH RATE: Motion during exposure, not to be confused with pitch, per se. However, pitch rate is similarly altitude-sensitive and therefore causes along-track image smearing.

ROLL: Movement of the vehicle about its longitudinal axis. This results in a change in attitude that alters the height of the camera over ground images; hence, it is an along-track error. However, note carefully the distinction between roll and roll rate with relation to image smear effect.

ROLL RATE: Motion during exposure. Since the actual movement leading to roll change in vehicle attitude is perpendicular to the line of flight, it is so recorded by the film, resulting in cross-track image smears.

YAW: Rotation from the line of flight of the longitudinal axis of the vehicle about its vertical axis.

YAW RATE: Motion during exposure. Since yaw and yaw rate are not altitude-sensitive, the resultant displacement of ground imagery is solely in a lateral direction and induces cross-track smearing.

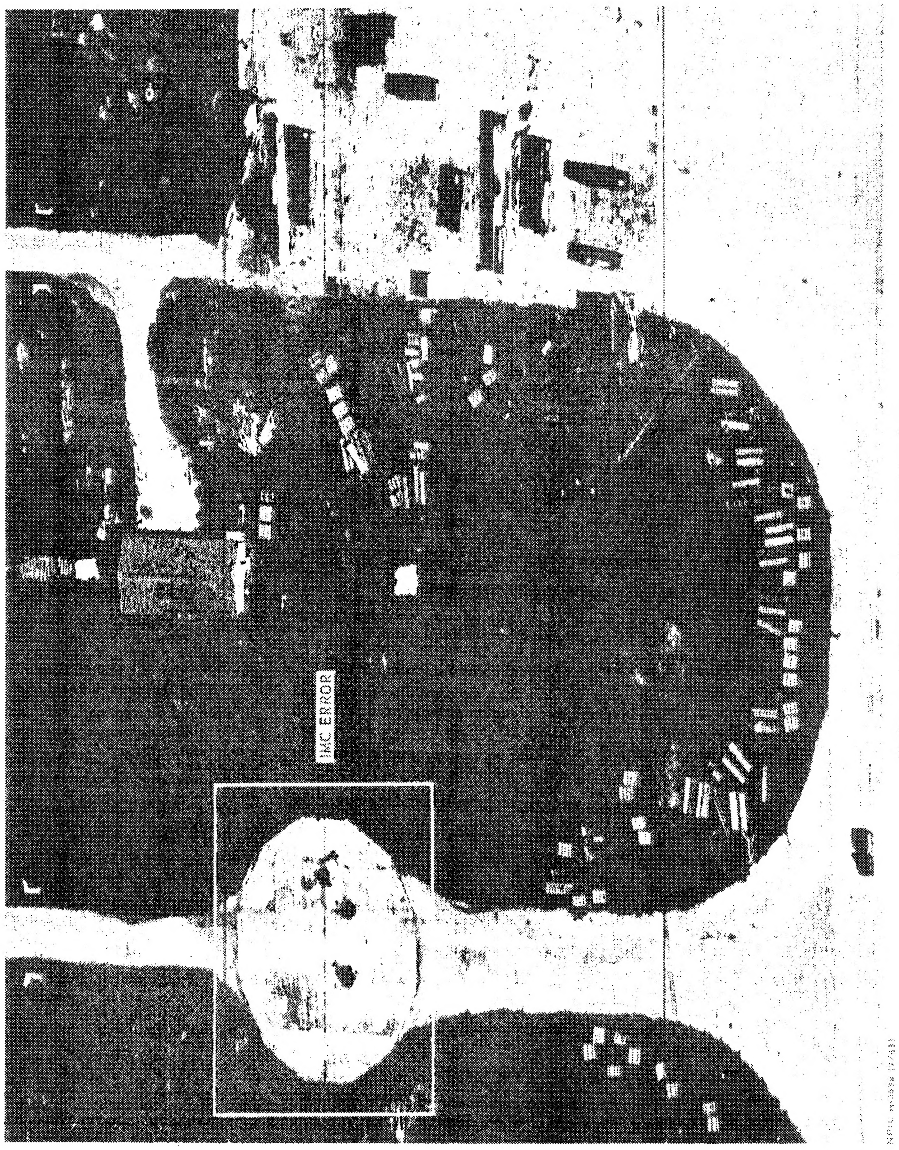

FIGURE 10. DISTORTION IN STRIP PHOTOGRAPHY.